Appendix D

Human Health Risk Assessment Methodologies

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Human Health Risk Assessment Methodology

The Waste Area Groups (WAGs) 6 and 10 (i.e., Operable Unit [OU] 10-04) baseline risk assessment (HHRA) is divided into three evaluations: a human health risk assessment (HHRA), an ecological risk assessment (ERA), and a qualitative Native American evaluation. The HHRA approach used in the BRA is based on the *EPA's Risk Assessment Guidance for Superfund (RAGS),* (EPA 1989a), the *INEL Track 2 Guidance Document* (DOE-ID 1994), and the *INEL Cumulative Risk Assessment Guidance Protocol* (INEL 1995). Similarly, the ERA approach used in this assessment is based on the *INEL Screening Level Ecological Risk Assessment Guidance Document* (VanHorn, Hampton, and Morris 1995). The qualitative Native American risk assessment prepared for WAG 6/10 is a pioneering effort that relied on direct input from the Shoshone-Bannock Tribes Risk Assessment Committee. The general approach taken by the Risk Assessment Committee is outlined in *Risk Assessment in Indian Country: Guiding Principles and Environmental Ethics of Indigenous People* (Shoshone-Bannock Tribes1996). This assessment is included as provided in Appendix A. The preliminary screening process performed before conducting the BRA is presented in Appendix C.

D-1. BASELINE RISK ASSESSMENT METHODOLGY

As discussed in the Idaho National Engineering and Environmental Laboratory (INEEL) cumulative risk assessment protocol (INEL 1995) the analysis methods used for the WAG comprehensive risk assessments are different than the risk assessments performed for a Track 1 or 2 (DOE-ID 1992, 1994). As discussed in this document, the analysis methods used in INEEL comprehensive risk assessments are often different from the analysis methods used in *INEL Track 1 and Track 2 Risk Assessments* (DOE-ID 1994). In general, the differences between the two types of analyses are present because comprehensive risk assessments are meant to analyze risks produced by multiple release sites within a WAG, while Track 1 and Track 2 risk assessments are only meant to analyze risks from one release site at a time. However, because OU 10-04 sites are geographically distributed across the INEEL (i.e., isolated from one another), sites will be evaluated one release site at a time similar to the Track 1 and 2 methodology. However, where sites are geographically located such that a potential to produce cumulative impact to air and groundwater exists, a "cumulative" assessment will be performed. This approach will satisfy the broader objective of INEEL comprehensive risk assessments and is consistent with the *INEL Cumulative Risk Assessment Guidance Protocol,* which recommends analyzing risks produced through the air and groundwater exposure pathways in a "cumulative" manner.

For those sites warranting a cumulative analysis, the air and groundwater exposure pathway analysis involves calculating one multi-site risk number for each contaminant of potential concern (COPC) in each air and groundwater exposure route (e.g., inhalation of fugitive dust, ingestion of groundwater, etc.). Analyzing the air and groundwater pathway in a cumulative manner, where appropriate, is necessary because contamination from multiple release sites may adversely affect pathways when the effects are cumulative.

Conversely, individual release sites are typically isolated from one another with respect to the soil pathway exposure routes (e.g., ingestion of soil, ingestion of homegrown produce, etc.). As a result, the guidance protocol recommends analyzing soil pathway exposures on a release-site-specific or "noncumulative" basis in INEEL comprehensive risk assessments.

The "comprehensive" and "cumulative" aspects of the OU 10-04 BRA are discussed more completely in the following sections. In general, the BRA is "comprehensive" because it evaluates risks

from all known and potential release sites within OU 10-04, and it is "cumulative" because risks from multiple release sites are evaluated in the groundwater exposure pathway, where geographically practicable.

With respect to the HHRA, the term "risk" is used throughout this section in a generic sense. Generally, the term is used to refer to the possibility of adverse health effects from either carcinogenic or noncarcinogenic contaminants; however, it is also used only when carcinogenic health effects are being discussed. The term "hazard quotient" (HQ) is used only when noncarcinogenic health effects are being discussed.

D-1.1 Human Health Risk Assessment

The human health exposure assessment quantifies the receptor intake of COPCs for complete pathways and exposure routes.

D-1.1.1 Conduct Exposure Assessment

The process of exposure assessment quantifies all receptor intakes of COPCs for selected pathways. The assessment consists of estimating for each site and COPC the magnitude, frequency, duration, and exposure route to humans and ecological receptors. The following exposure assessment tasks were performed as part of the BRA process:

- Identification and characterization of exposed populations
- Identification of complete exposure pathways
- Estimation of contaminant concentrations at points of exposure (see Appendix C)
- Estimation of human intake rates
- Calculation of carcinogenic risk and noncarcinogenic hazard quotients.

Each of these activities is discussed in the following sections.

D-1.1.2 Identification and Characterization of Exposed Populations

The following human populations could potentially be exposed to contaminants found at or originating from OU 10-04:

D-1.1.2.1 Workers. The INEEL will remain under governmental control for the next 100 years; therefore, workers at the site are potential receptors. The following two occupational exposure scenarios are analyzed in the BRA:

- A current occupational scenario that lasts for 25 years from the present
- A future occupational scenario that starts in 100 years and lasts for 25 years.

D-1.1.2.2 Residents. Portions of the INEEL will potentially be released to the public after 100 years of operations; consequently, residential development must be considered as a potential future use of the site.

The residential exposure scenario considers a future resident that moves to the site in 100 years and lives there for 30 years.

As a conservative assumption, future residents are expected to construct 3-m (10-ft) basements beneath their homes. As a result, all contamination detected in the upper 3 m (10 ft) of each release site will be evaluated for surface pathway exposures. This analysis method will hereafter be referred to as a "residential intrusion scenario."

D-1.1.3 Evaluation of Exposure Pathways

Once potentially exposed populations have been identified and characterized, exposure pathways can be traced from the site to the exposed populations. Each exposure pathway describes a mechanism by which a population or individual could be exposed to contaminants originating from one or more release sites at OU 10-04. Only those exposure pathways deemed to be complete (i.e., where a plausible route of exposure can be demonstrated from the site to the receptor) are quantitatively evaluated in the BRA.

Based on information presented in the OU 10-04 conceptual site models (CSMs) (Figures D-1 and D-2), the following exposure scenarios, exposure pathways, and exposure routes will be evaluated in the BRA:

- Exposure scenarios
  - Current occupational
  - Future occupational
  - Residential intrusion
- Exposure pathways
  - Groundwater
  - Air captured
- Soil. exposure routes
  - Ingestion
    - Soil
    - Groundwater (residential intrusion scenario only)
    - Home grown produce (residential intrusion scenario only)
  - Inhalation
    - Fugitive dust
    - Volatiles from Soil
    - Volatiles from Indoor Groundwater Use (residential intrusion scenario only)

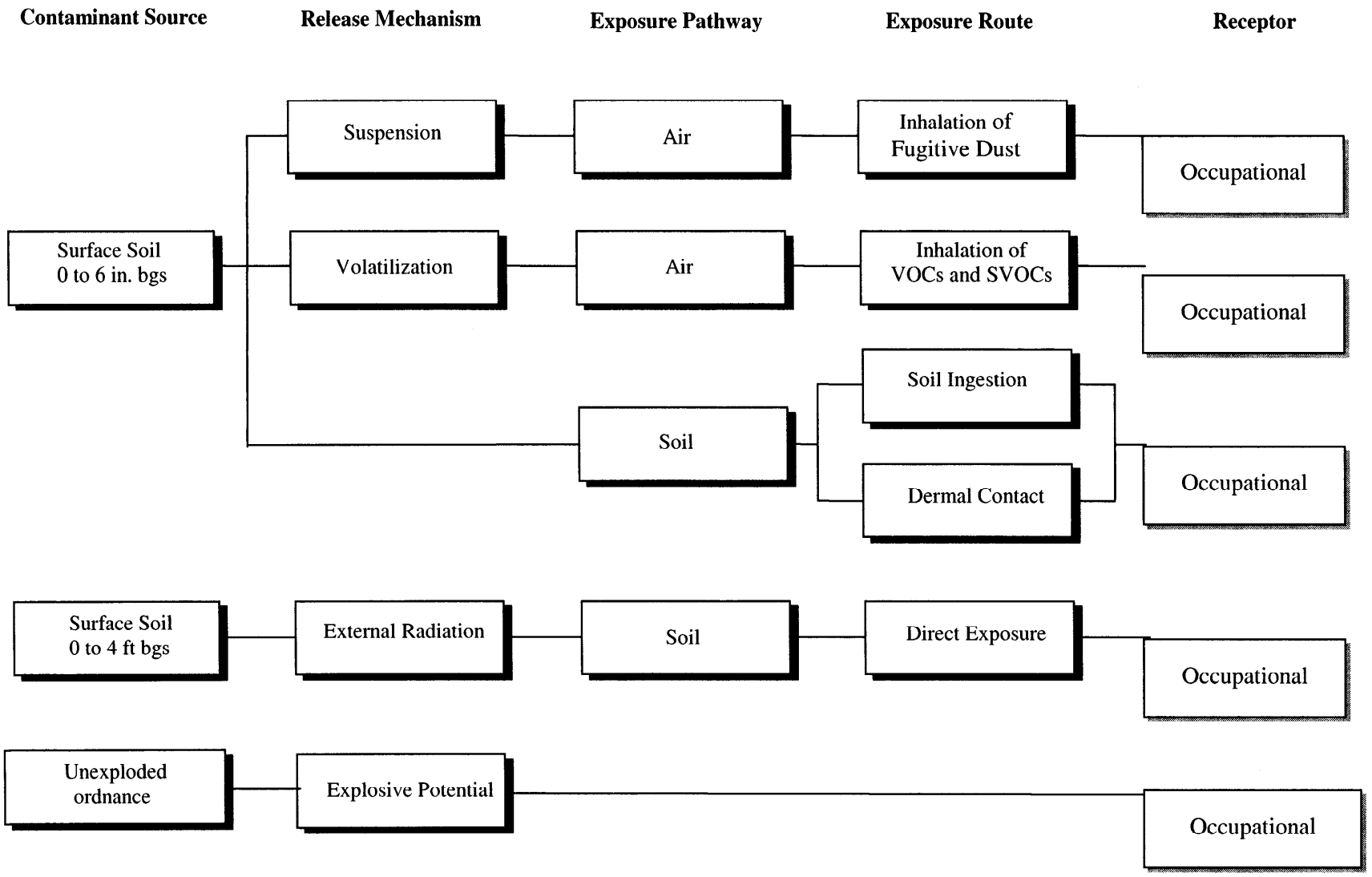

Figure D-1. Occupational exposure scenario conceptual site model (CSM.)

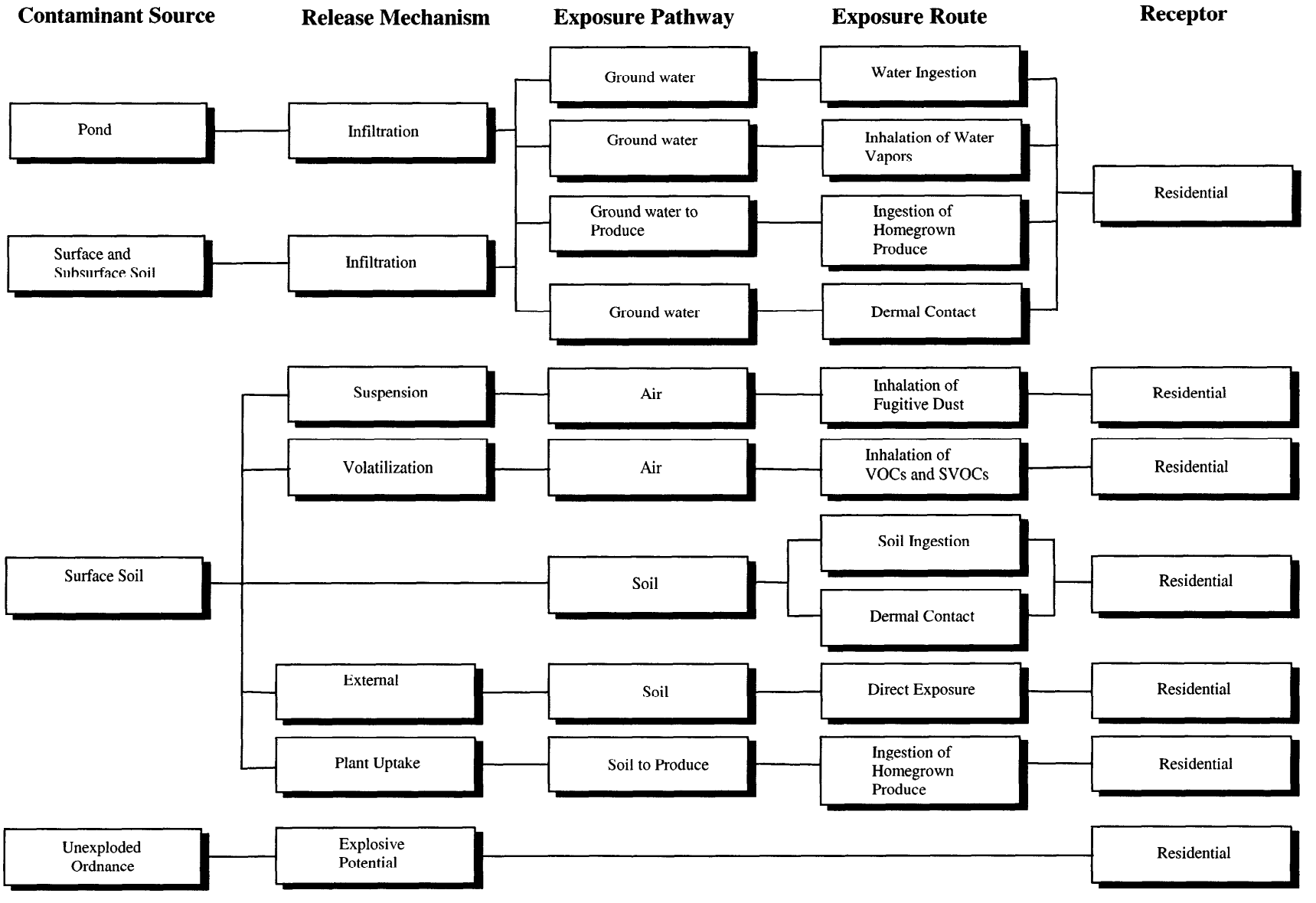

Figure D-2. Residential exposure scenario CSM.

- Dermal absorption
  - Soil
  - Groundwater (residential intrusion scenario only)
- External radiation exposure.

Cumulative risk assessment strategies are used for the following exposure routes: ingestion of groundwater, inhalation of fugitive dust, inhalation of volatile COPCs from soil, inhalation of volatile COPCs from groundwater, external radiation exposure, and dermal absorption of groundwater. This cumulative methodology is set out in the *Guidance Protocol for the Performance of Cumulative Risk Assessments at the INEL* (LMITCO 1995). All other exposure routes were examined on a site-by-site basis.

In general, the residential exposure scenario evaluates only adult exposures. The reason for this limitation is that the risk results presented in the BRA are calculated, using very conservative exposure assumptions. These assumptions would most likely cause the risk calculations to overestimate the actual risks to sensitive subpopulations, such as children. The exception to this rule is associated with the soil ingestion exposure route. Under this exposure route, six years of childhood soil ingestion and 24 years of adult soil ingestion are included in the contamination intake calculation. Soil ingestion is the most critical exposure route for children, who may someday live at OU 10-04, because of the relatively large amount of soil that children can ingest.

The soil ingestion intake factor equations for both the occupational and the residential scenarios are presented below in Equations D-1 and D-2.

$$\text{Intake Rate}_{\text{residential, soil ingestion}} = \frac{C_{soil} * FI * EF_a * CF}{AT} * \left(\frac{IRS_a * ED_{as}}{BW_a} + \frac{IRS_c * ED_{cs}}{BW_c} \right) \qquad \text{(D-1)}$$

where:

C_{soil} = contaminant concentration in soil, contaminant dependent, (mg/kg or pCi/g)

FI = fraction ingested from contaminated source, (default = 100 percent)

EF_a = exposure frequency, adult, (350 days/year)

CF = conversion factor, nonradionuclide (1E-6 kg/mg), radionuclide (1E-3 g/mg)

AT = averaging time, noncarcinogenic (1.05E4 days), carcinogenic (2.45E4 days)

$IRS_{a/c}$ = soil ingestion rate, adult (100 mg/day), child (200 mg/day)

$ED_{as/cs}$ = exposure duration, adult soil (24 years), child soil (6 years)

$BW_{a/c}$ = body weight, adult (75 kg), child (15 kg)

$$\text{Intake Rate}_{\text{worker, soil ingestion}} = \frac{C_{soil} * FI * EF_w * CF * IRS_w * ED_w}{AT * BW_a} \quad \text{(D-2)}$$

where:

EF_w = exposure frequency, worker, (250 days/year)

IRS_w = soil ingestion rate, worker (50 mg/day)

ED_w = exposure duration, worker (25 years)

The equation for the radionuclides does not include the denominator in either equation.

Carcinogenic and noncarcinogenic COPC intakes from soil ingestion for the residential scenario, the current worker scenario, and the future worker scenario are presented in Appendix E.

Risks and hazard quotients are calculated from the intakes above by adjusting the intakes with the oral SFs and RfDs, respectively. Risks and hazard quotients from soil ingestion for the residential scenario, for the current worker scenario, and for the future worker scenario are presented in Appendix E.

D-1.1.3.1.1 Homegrown Produce Ingestion Methodology—The homegrown produce ingestion exposure route includes an evaluation of COPC concentrations in plants caused by both root uptake and irrigation with contaminated groundwater. The homegrown produce ingestion pathway is evaluated on a site-by-site basis since residents are not likely to be growing produce at more than one site at a time. At each retained site, the total source concentration evaluated in the homegrown produce ingestion exposure route is calculated by combining exposure point concentration with the soil concentration that would result from equilibrium partitioning between soil and groundwater contaminated with the COPC.

Homegrown produce concentrations assumed for each COPC are presented in Appendix E. Radionuclide concentrations are estimated at the start of the residential exposure period of 100 years in the future, rather than an average of 100–130 years. To evaluate the average soil concentration of radioactive COPCs in soil when irrigating with groundwater, the integrated form of Equation 5.39 in *Nuclear Regulatory Commission (NRC) Guidance Document* (NRC 1993) is used:

$$C_s(t) = \frac{\frac{\dot{I}_v}{L_i + \lambda}\left(t_e + \frac{e^{-(L_i+\lambda)t_e}}{L_i + \lambda}\right) + \frac{C_{so}}{L_i + \lambda}\left(1 - e^{-(L_i+\lambda)t_e}\right) - \frac{\dot{I}_V}{(L_i + \lambda)^2}}{t_e} \quad \text{(D-3)}$$

where

$C_s(t)$ = the average concentration of a COPC in soil for the exposure period, t_e (pCi/g)

$\dot{I}v$ = COPC input rate from irrigation (pCi-day/g)

L_i = leach rate constant $(day)^{-1}$

λ = radioactive decay rate constant $(day)^{-1}$

t_e = exposure period (10,950 day [30 years * 365 days/year])

C_{so} = average concentration of COPC in the top 3 m (10 ft) of soil at the start of the residential exposure period (pCi/g).

For nonradioactive COPCs, this equation reduces to the following:

$$C_s(t) = \frac{\frac{\dot{I}_v}{L_i}\left(t_e + \frac{e^{-(L_i t_e)}}{L_i}\right) + \frac{C_{so}}{L_i}\left(1 - e^{-(L_i t_e)}\right) - \frac{\dot{I}_v}{L_i^2}}{t_e} \quad \text{(D-4)}$$

The COPC input rate from irrigation is given by the following equation:

$$\dot{I}_V = C_W \times \frac{I_R}{\rho \times T} \quad \text{(D-5)}$$

where

$\dot{I}_v$ = COPC input rate from irrigation (mg-day/g or pCi-day/g)

C_W = average concentration of a COPC in groundwater for the exposure period (mg/L or pCi/L)

I_R = irrigation rate (8.47 L/m^2-yr × 90 days/365 yrs) (Maheras et al. 1994)

ρ = soil density (1.5E+06 g/m^3)

T = thickness of root zone (0.2 m [7 in.]) (International Atomic Energy Agency [IAEA] 1994).

The leach rate constant is given by the following equation (Baes and Sharp 1983):

$$L_i = \frac{P}{\theta_c \times \left(1 + \frac{K_d \times \rho}{\theta_c}\right) \times T} \times CF \quad \text{(D-6)}$$

where

P = net water percolation rate (0.86 m/1 year) (infiltration rate of 0.1 m/1 year, as presented in *INEL Track 2 Guidance* [DOE-ID 1994], plus the contribution from irrigation)

θ_c = volumetric water content in source volume (0.41 m^3/m^3) (Rood 1994)

K_d = COPC-specific soil-to-water partition coefficient (cm^3/g)

ρ = soil density (1.5 g/cm^3)

T = thickness of root zone (0.2 m) (IAEA 1994)

CF = conversion factor (1 year/365 days).

The radioactive decay constant is given by the following equation:

$$\lambda = \frac{\ln 2}{T_{1/2}} \quad \text{(D-7)}$$

where

$T_{½}$ = half-life of a radionuclide (d).

Finally, concentrations of COPCs in affected homegrown produce are calculated using the following equation (EPA 1995):

$$C_p(t) = C_s(t) \times B_v \quad \text{(D-8)}$$

where

$C_p(t)$ = average concentration of a COPC in homegrown produce from root uptake (pCi/g or mg/kg)

$C_s(t)$ = average concentration of a COPC in soil for the exposure period (pCi/g or mg/kg)

B_v = COPC-specific soil-to-plant uptake coefficient (mass of COPC/dry mass of plant material per mass of COPC/dry mass of soil).

Homegrown produce contaminant concentrations calculated using the above equations are presented in Appendix E.

Intake rates from homegrown produce ingestion are calculated using the equations presented below.

$$\text{Intake Rate}_{\text{residential, HGP}} = \frac{C_{\text{produce}} * IRP * EF_a * ED_a * CF}{AT} \quad \text{(D-9)}$$

where

$C_{produce}$ = concentration of COPC in homegrown produce

IRP = Intake rate produce, radionuclides (1.67E1 g/day), nonradionuclides (2.76E-1 g/kg-day)

CF = conversion factor, nonradionuclides (1E-3 kg/g), radionuclides (1)

Carcinogenic and noncarcinogenic COPC intakes from homegrown produce ingestion for the residential scenario, the current worker scenario, and the future worker scenario are presented in Appendix E.

Risks and hazard quotients are calculated from the intakes above by adjusting the intakes with the oral SFs and RfDs, respectively. Risks and hazard quotients from homegrown produce ingestion for the

residential scenario, for the current worker scenario, and for the future worker scenario are presented in Appendix E.

D-1.1.3.1.2 External Radiation Exposure Methodology—The Environmental Protection Agency (EPA) classifies all radionuclides as human carcinogens. Exposure levels, based on carcinogenic risk, are typically more conservative than those based on systemic toxicity for the same radionuclide. Therefore, only carcinogenic risk is evaluated as part of this methodology. The external radiation exposure pathway is examined using the cumulative risk assessment strategies since radiation from multiple populations or sites within a group may present a risk to worker or residents.

For the external radiation exposure route, standard EPA protocols are used to estimate risks for all retained sites. In other words, external radiation exposure risks are calculated by multiplying radiation intakes for specific isotopes by the radionuclide SFs presented in EPA's Health Effects Assessment Summary Tables (EPA 1994). The standard EPA protocols are used because all of the retained sites in the BRA have radionuclide contamination that is at least 0.2-m (6-in.) thick over a large area. This thickness is large enough to satisfy the assumption that an increase in source thickness will not cause an increase in surface radiation exposures.

Average exposure point concentrations from 100–130 years in the 0–3 m (0–10) ft depths were used for the residential scenario, from 0–25 years in the 0–1.2 m (0–4 ft) depths for the current worker scenario, and from 100–125 years in the 0–1.2 m (0–4-ft) bins for the future worker scenario. These average exposure point concentrations are presented in Appendix E.

Equations D-10 and D-11 below show how exposure factors were calculated for the external radiation exposure route.

$$\text{Intake Rate}_{\text{residential, ext rad}} = C_{soil} * ET_a * EF_a * ED_a * CF \qquad \text{(D-10}$$

where

C_{soil} = average radionuclide decayed exposure point concentrations for years 100–130 (pCi/g)

CF = conversion factor (1.14e–4 years/hour)

ET_a = exposure time, adult (24 hours/day)

$$\text{Intake Rate}_{\text{worker, ext rad}} = C_{soil} * ET_w * EF_w * ED_w * CF \qquad \text{(D-11)}$$

where

C_{soil} = average radionuclide decayed exposure point concentration for years 0–25 for the current worker scenario and for years 100–125 for the future worker scenario (pCi/g)

ET_w = exposure time, worker (8 hours/day)

Carcinogenic COPC exposure factors from external radiation exposure for the residential scenario, for the current worker scenario, and for the future worker scenario are presented in Appendix E.

Risks are calculated from the intakes above by adjusting the exposure factors with the external SF taken from the HEAST tables. Risks from external radiation exposure for the residential scenario, the current worker scenario, and the future worker scenario are presented in Appendix E.

D-1.1.3.1.3 Dermal Exposure Methodology—Risks from dermal absorption of soil are driven by a contaminant's potential for being absorbed through skin. This potential is quantified by a contaminant's dermal absorption factor (i.e., the fraction of a given contaminant that can be absorbed through skin [ABS]). ABS values are not well quantified for many of the contaminants that have been detected at OU 10-04 sites; however, EPA Region 9 has issued general guidelines for default ABS values (EPA 1999a).

Organic contaminants have the greatest potential for producing unacceptable dermal absorption from soil exposures. The reason for this distinction is that, in general, organic contaminants have relatively high ABS values. Therefore, the dermal absorption pathway is evaluated for organic contaminants and arsenic. EPA (1999) recommends assuming an ABS value of 10% for semivolatile organic contaminants; however, EPA (1999) does not recommend the use of assumed or default ABS values for volatile or inorganic contaminants. This approach is different from past guidance. The recommended ABS values from EPA (1999) are used for this evaluation.

Equation D-12 below shows how dermal absorption intakes were calculated for the dermal absorption exposure route.

$$\text{Dermal absorption, residential} = \frac{Csoil \times SA_{as} \times AF_a \times EF \times ED \times CF}{BW \times AT} \qquad \text{(D-12)}$$

where

C_{soil} = average exposure point concentration of COPC in soil (mg/kg)

SA_{as} = skin surface area available for contact, adult (5700 cm^2/event)

AF_a = soil to skin adherence factor, adult (0.2 mg/cm^2)

ABS = absorption factor (unitless)

CF = conversion factor (1E–06 kg/mg)

$$\text{Dermal absorption worker} = \frac{Csoil \times SA_{as} \times AF_a \times EF \times ED \times CF}{BW \times AT}$$

where

SA_{ws} = skin surface area available for contact, worker (3300 cm^2/event)

AF_w = soil to skin adherence factor, worker (0.07 cm^2/event)

Carcinogenic and noncarcinogenic COPC intakes from dermal absorption for the residential scenario, for the current worker scenario, and for the future worker scenario are presented in Appendix E.

Absorbed dose for the dermal absorption exposure route is similar to contaminant intakes for other exposure routes. However, oral toxicity numbers are more available than the dermal toxicity numbers. Therefore, the risk and HQs are calculated, using the oral slope factors and reference doses, and adjusted

with a gastrointestinal absorption efficiency factor (GI). The GI was defaulted to 0.05 based on guidance in Appendix A of the EPA Risk Assessment Guidance Manual (EPA 1989). This guidance states that a relatively conservative assumption for oral absorption in the absence of appropriate information would be 5%. Currently, Region 9 discusses the use of oral toxicity values for evaluating dermal exposures for their route-to-route extrapolations methods (EPA 1999a). They state that for many chemicals, a scientifically defensible data base does not exist for making this conservative an adjustment of the oral slope factor/RfD to estimate a dermal toxicity value. Region 9 uses the current guidance (EPA 1999b), which recommends that cadmium be the only contaminant requiring an adjustment factor. The 1999 Region 9 PRG calculations for cadmium are based on this adjustment. The 10-04 risk assessment continued to conservatively apply the 5% adjustment to all appropriate COPCs. Risks and HQs for dermal absorption exposures are calculated, using equations D-13 and D-14.

$$\text{Risk} = \text{AD} \times \text{SF} / \text{GI} \qquad \text{(D-13)}$$

where

Risk = contaminants specific carcinogenic risk (unitless)

SF = contaminant specific oral slope factor [$(\text{mg/kg-d})^{-1}$].

GI = gastrointestinal absorption efficiency factor (0.05)

$$\text{HQ} = \frac{\text{AD}}{\text{RfD}} * \text{GI} \qquad \text{(D-14)}$$

where

HQ = contaminant specific noncarcinogenic hazard quotient (unitless)

RfD = contaminant specific oral reference dose (mg/kg-d).

Risks and hazard quotients are calculated from the intakes above by adjusting the intakes with the oral SFs and RfDs, respectively. Risks and hazard quotients from dermal absorption for the residential scenario, the current worker scenario, and the future worker scenario are presented in Appendix E.

D-1.1.3.2 Soil Pathway Assumptions. The HHRA soil pathway analysis includes the following assumptions:

- Soil pathway exposures from multiple release sites are insignificant.
- The likelihood that a future resident will raise meat and dairy products on a residential lot at OU 10-04 is assumed to be negligible, in accordance with INEEL guidance on analysis of the homegrown produce ingestion exposure route (LMITCO 1996). As a result, risks from the ingestion of meat and dairy products are not quantitatively evaluated in the BRA.
- A receptor is assumed to be present at each retained site for the full exposure duration (30 years for a residential receptor and 25 years for an occupational receptor), with the exception of a two-week vacation for the residential scenario.

D-1.1.3.3 Air Pathway Methodology. All retained sites that have contamination in the top 3 m (10 ft) of soil are assumed to have a contaminant source that can be released into the air pathway. The exposure routes that are evaluated as part of the air pathway analysis are as follows:

- Inhalation of fugitive dust
- Inhalation of volatiles.

Because of the isolated nature of the OU 10-04 release sites, the air pathway is evaluated on a site-by-site basis similar to that of the soil pathway unless the potential for cumulative impacts exists (i.e., sites located geographically close to one another). Sites evaluated as a group include Liquid Corrosive Chemical Disposal Area (LCCDA)-01 and –02; Mine Fuze population 2 and 3; Boiling Water Reactor Experiment (BORAX)-01, -02, -08 and –09; Experimental Breeder Reactor (EBR)-08 and -10; Fire Station populations 2, 3, and 4; National Oceanic and Atmospheric Administration (NOAA) populations; and Naval Ordnance Disposal Facility (NODA) populations. Areas evaluated on a site-by-site basis include the Rail Car Area, Field Station, Craters, Burn Ring, and Organic-Moderated Reactor Experiment.

The concentration of each COPC in the respirable particulate matter is assumed to equal the average soil concentration. Averaging contaminant concentrations above the site for the air pathway produces one contaminant-specific risk estimate for each air pathway exposure route (i.e., for each time period, each air pathway exposure route has the same risk or hazard index [] at every retained site).

Equation D-15 below shows how the fugitive dust concentration was calculated.

$$C_{air} = CF \times R \times C_{soil} \qquad \text{(D-15)}$$

where

C_{air} = contaminant concentration in air as fugitive dust (mg/m^3 or pCi/m^3)

CF = conversion from kg to mg for nonradionuclides or g to mg for radionuclides

R = airborne respirable particulate matter concentration (0.013 mg/m^3). Value is given in Appendix B of the *INEL Site Environmental Monitoring Reports* (e.g., Hoff et al. 1993), and represents the grand mean from all the sites monitored at the INEEL.

Equation D-16 is used for estimating concentrations of airborne volatiles.

$$C_{air} = \frac{\Sigma (C_n / VF_n) A_n}{A_T} \qquad \text{(D-16)}$$

where

C_{air} = contaminant concentration in air as volatiles (mg/m^3)

C_n = contaminant soil concentration at site *n* (mg/kg)

VF_n = volatilization factor (as described in *INEL Track 2 Guidance* [DOE-ID 1994]) for site *n* (m^3/kg)

A_n = surface area of site *n* (m^2)

A_T = total area of the site *n* (m^2).

These equations produce conservatively high estimates of airborne COPC concentrations because no credit is taken for dilution of airborne concentrations caused by dust blown from uncontaminated areas of the INEEL.

As with the soil pathway analysis, the air pathway receptor is either a current or future occupational worker (who is assumed to be exposed for 25 years) or a hypothetical future resident (who is exposed for 30 years).

Intakes of fugitive dust are calculated using the equations presented below for workers and residents.

$$\text{Intake}_{\text{residential, fugitivedust}} = \frac{C_{air} * IRI * EF_a * ET_a * ED_a}{BW_a * AT} \quad \text{(D-17)}$$

where

C_{air} = concentration of contaminant in the air as fugitive dust (mg/m3 or pCi/m^3)

IRI = inhalation intake rate, (0.83 m^3/hr) (D-18)

$$\text{Intake}_{\text{worker, fugitivedust}} = \frac{C_{air} * IRI * EF_w * ET_w * ED_w}{BW_a * AT}$$

Intakes of volatiles from the soil are calculated, using equations similar to those presented above for workers and residents fugitive dust intake. However, the variable C_{air} in the inhalation of volatile COPC exposure route represents the contaminant concentration in air as a volatile COPC in mg/m^3.

Carcinogenic and noncarcinogenic COPC intakes from inhalation of fugitive dust for the residential scenario, the current worker scenario, and the future worker scenario are presented in Appendix E. Carcinogenic and noncarcinogenic COPC intakes from inhalation of volatiles from soil for the residential scenario, for the current worker scenario, and for the future worker scenario are presented in Appendix E.

Air pathway risks and HQs are calculated at 0 and 100 years in the future for the occupational scenario, and at 100 years in the future for the residential scenario. Risks and hazard quotients are calculated from the intakes above by adjusting the intakes with the inhalation SFs and RfDs, respectively. Risks and hazard quotients from the inhalation of fugitive dust for the residential scenario, for the current worker scenario, and for the future worker scenario are presented in Appendix E. Risks and hazard quotients from the inhalation of volatiles from soil for the residential scenario, the current worker scenario, and the future worker scenario are presented in Appendix E.

D-1.1.3.3.1 Air Pathway Assumptions—The HHRA air pathway analysis includes the following assumptions:

- The concentration of each retained contaminant in the respirable particulate matter above the OU 10-04 site will be equal to each contaminant's site-wide average soil concentration.

- The airborne concentration of each retained contaminant will be the same at every point inside the site boundaries.

- The air pathway receptor will be assumed to spend the entire exposure duration (25 years for current occupational workers and 30 years for future residents) working or living within the boundaries of the site, with the exception of a two week per year vacation for the residential scenario.

D-1.1.3.4 Groundwater Pathway Methodology. To quantify risks for the future residential receptor (there is no occupational receptor for this exposure pathway), modeling of contaminant concentrations in groundwater is required. For the groundwater pathway analysis, every contaminant that is not eliminated by the contaminant screening process is assumed to have the potential for migrating to groundwater, but only manmade sources of contamination are considered in the analysis. The following exposure routes are evaluated as part of the groundwater pathway analysis:

- Ingestion of groundwater

- Dermal absorption of groundwater

- Inhalation of volatiles produced by indoor use of groundwater.

Groundwater pathway risks are calculated at 100 years in the future for use in the 100-year residential exposure scenario.

The groundwater pathway is another set of exposure routes that are evaluated, using the cumulative methodology. Areas evaluated on a site by site basis include: LCCDA-01 and –02; Mine Fuze population 2 and 3; Borax-01, -02, -08 and –09; EBR-08 and –10; Fire Station populations 2, 3, and 4; NOAA populations; and NODA populations. Sites evaluated as a group include the Rail Car Area, Field Station, Craters, and Burn Ring

Groundwater concentrations resulting from surface and near surface sources are estimated using the computer code GWSCREEN (Rood 1994). For each COPC, GWSCREEN produces groundwater concentrations versus time as the codes output. From this output, the maximum 30-year average groundwater concentration of each COPC and the 30-year average concentrations at 100 years in the future are calculated. The average concentrations at year 100 are used to calculate groundwater pathway risks for the residential exposure scenario, and the maximum average concentrations are used to calculate maximum expected groundwater risks.

The total mass of each contaminant, considered in the GWSCREEN modeling, is calculated by summing the contaminant masses from the retained sites. The contaminant mass at each retained site is derived by multiplying the contaminant's 95% UCL of the mean concentration (or maximum concentration if the maximum is less than the 95% UCL) by the mass of contaminated soil at the site. For example, if a contaminant has a 95% UCL of the mean concentration of 5 mg/kg at three release sites with dimensions of $10 \times 10 \times 1$ m ($30 \times 30 \times 3$ ft), the mass of the contaminant that would be used in the GWSCREEN modeling would be 2.3E+06 mg [(3 sites) × (5 mg/kg/site) × (10 m) × (10 m) × (1 m) × (1E+06 cm^3/m^3) × (1.5 g/cm^3) × (1E–03 kg/g) = 2.3E+06 mg]. Values assigned to various GWSCREEN input parameters and the COPC masses used in the GWSCREEN modeling are shown in Appendix E. Other information about how GWSCREEN calculates groundwater concentrations is included in the Track 2 Guidance (DOE-ID 1992).

Three input parameters shown in Appendix E (length of source parallel to flow, width of source perpendicular to flow, and thickness of source) are based on the site dimensions shown in Appendix E. The length and width values were taken from Track 1 and Track 2 documents and from previous sampling activities. The thickness of the contaminated area is the maximum depth at which sampling occurred.

Appendix E contains the results of the GWSCREEN runs. The GWSCREEN results are assumed to be conservative estimates of the maximum groundwater concentrations that might occur at any point beneath a retained site or group of sites if geographically in the same area of the INEEL during the residential exposure scenario.

The contaminant concentrations shown in Appendix E are expected to overestimate the true aquifer concentrations that will be produced by infiltration of contaminants at OU 10-04. Because of the great complexity of the subsurface beneath the INEEL and limited information about factors that influence flow and transport of contaminants in groundwater, the uncertainty about potential contaminant concentrations, associated with the groundwater pathway exposure routes, is greater than the uncertainty associated with any other exposure pathway in this BRA. To compensate for this relatively large uncertainty, conservative assumptions are used throughout the groundwater pathway analysis. Some of the conservative assumptions that are used in the GWSCREEN analysis are as follows:

- All infiltration is assumed to occur through contaminated areas of the site(s).

- GWSCREEN uses a plug flow model for contaminant transport through the unsaturated zone. This model does not take any credit for contaminant dispersion in the unsaturated zone.

- Groundwater flow through fractured basalt in the unsaturated zone is assumed to occur very rapidly in comparison to flow through sedimentary material. This assumption is incorporated into the GWSCREEN modeling by using a depth to the aquifer that is only 1/10th of the total unsaturated zone thickness beneath OU 10-04. Using this small depth results in a relatively short unsaturated zone travel time in which radioactive decay can occur. As a result, the GWSCREEN estimates of radionuclide concentrations are expected to be conservatively high. Since no loss mechanisms are assumed to be present for nonradioactive contaminants, the only affect that the small unsaturated zone thickness assumption has on these contaminants is that it reduces the time at which the contaminants are predicted to reach the aquifer. The assumption has no effect on the predicted contaminant concentrations in the aquifer after the contaminants have reached the saturated zone.

- All COPC mass contained in surface soils is assumed to contribute to groundwater contamination. For the purposes of the GWSCREEN modeling, no credit is taken for loss of COPC mass caused by mechanisms such as wind erosion, surface water erosion, or contaminant uptake into plants. The only contaminant loss mechanism that is considered in the groundwater pathway evaluation is radioactive decay.

- Estimates of COPC mass that may be transported to groundwater are based on upper limit estimates of COPC soil concentrations.

Two other conservative assumptions that are included in the groundwater analysis, but not limited to the GWSCREEN modeling, are as follows:

- The groundwater receptor is assumed to take all drinking water from a well, located at the center of the equivalent rectangle's downgradient edge, for 30 years.

- All contaminants are assumed to be uniformly distributed within the groundwater modeling source volume.

D-1.1.3.5 Dermal Absorption From Groundwater Methodology. Exposures to COPCs through dermal absorption of groundwater are controlled by a given contaminants permeability coefficient of water through skin (K_p^w). According to EPA guidance (EPA 1992b), if the permeability coefficient for a given COPC is less than 0.1 cm/hour, then the dermal absorption from groundwater exposure route produces risks that are less than risks produced by the groundwater ingestion exposure route for that COPC. In the HHRA, the default permeability coefficient used for inorganic COPCs is 1E–03 cm/hour, and the permeability coefficients for organic COPCs are estimated using the following equation:

$$\text{Log } K_p^w = -2.72 + 0.71 \text{ Log } K_{ow} - 0.0061 \text{ MW} \qquad \text{(D-19}$$

where

K_{ow} = octanol/water partition coefficient (unitless)

MW = molecular weight (g/mol).

Permeability coefficients for OU 10-04 COPCs are shown in Appendix E. If an organic COPC has a permeability coefficient greater than the screening level of 0.1 cm/hour, the dermal absorption from the groundwater exposure route is quantitatively evaluated in the HHRA. Contaminant intakes for this exposure route are calculated using the equation shown below.

$$\text{Intake}_{\text{residential, absorption groundwater}} = \frac{C_{water} * SA_{aw} * ETW_a * EF_a * ED_a * DP * CF}{BW_a * AT} \qquad \text{(D-20)}$$

where

C_{water} = concentration of COPC in groundwater, calculated from the GW Screens (mg/L)

SA_{aw} = Skin surface area available for contact with groundwater, (20,000 cm^2/event) from EPA Region 9 preliminary remediation goal (PRG) tables

ETW_a = exposure time for bathing (0.25 hours per day)

DP = dermal permeability, COPC specific (cm/hr)

CF = conversion factor (1 L/1000 cm^3).

Carcinogenic and noncarcinogenic COPC intakes from dermal absorption of groundwater are presented in Tables E-1-43 and E-1-44 for the residential scenario. These tables are presented in Appendix E.

Risks and HQ's from the intakes described above are calculated similar to the dermal absorption of soil. Risks and hazard quotients from the dermal absorption of groundwater are presented in Tables E-1-2 and E-1-23.

D-1.1.3.6 Ingestion of Groundwater Methodology. The groundwater ingestion exposure route is very similar to the soil ingestion exposure route. The equation used to calculate the intake of groundwater is presented below.

$$\text{Intake}_{\text{residential, groundwater ingestion}} = \frac{C_{water} * IRW_a * EF_a * ED_a * FI}{BW_a * AT} \qquad \text{(D-21)}$$

where

C_{water} = COPC concentration in the groundwater (mg/L or pCi/L)

IRW_a = Intake rate of water, adult (2 L/day)

Carcinogenic and noncarcinogenic COPC intakes from the ingestion of groundwater are presented in Appendix E for the residential scenario.

Risks and hazard quotients are calculated from the intakes above by adjusting the intakes with the oral SFs and RfDs, respectively. Risks and hazard quotients from the ingestion of groundwater are presented in Appendix E.

D-1.1.3.7 Inhalation of Volatiles from Indoor Groundwater Use. In the HHRA, exposures caused by the inhalation of water vapors from indoor water use are calculated based on experimental data derived from a study of household water contaminants (Andelman 1990). This study derived a volatilization constant that defines the relationship between the concentration of a contaminant in household water and the average concentration of the volatilized contaminant in air. In the derivation, all uses of household water were considered (e.g., showering, laundering, and dish washing), and certain reasonable assumptions were made in deriving a volatilization fraction. For example, the study included assumptions about water usage for a family of four, the volume of the dwelling, and the air exchange rate. Furthermore, the study assumed that the average transfer efficiency weighted by the type of water use is 50% (i.e., half of the concentration of each chemical in water will be transferred into air by all types of water uses).

In the HHRA indoor water use analysis, a central tendency value (6.50E–02 mg/m^3 air per mg/L water [Andelman 1990]) for the volatilization fraction of a COPC is used to develop estimates of COPC airborne concentrations. The airborne concentrations are calculated by multiplying the central tendency value by the COPC groundwater concentrations shown in Appendix E. These concentrations are then used to develop contaminant intake estimates using the equations shown below.

$$\text{Intake}_{\text{residential, volatiles from groundwater}} = \frac{C_{air} * IRI * EF_a * ET_a * ED_a}{BW_a * AT}$$

(D-22)

where

C_{air} = concentration of volatiles in the air from indoor groundwater use (mg/m^3)

Carcinogenic and noncarcinogenic COPC intakes from the inhalation of volatiles from indoor groundwater use are presented in Appendix E for the residential scenario.

Risks and hazard quotients are calculated from the intakes above by adjusting the intakes with the inhalation SFs and RfDs, respectively. Risks and hazard quotients from the inhalation of volatiles from indoor groundwater use are presented in Appendix E.

D-1.1.4 Conduct Toxicity Assessment

Toxicity assessment is the process of characterizing the relationship between the dose or intake of a substance and the incidence of an adverse effect in the exposed population. Toxicity assessments evaluate results from studies with laboratory animals or from human epidemiological studies. These evaluations are used to extrapolate from high levels of exposure, where adverse effects are known to occur, to low levels of environmental exposures, where effects can only be predicted based on statistical probabilities. The results of these extrapolations are used to establish quantitative indicators of toxicity.

Health risks from all routes of exposure are characterized by combining the chemical intake information with numerical indicators of toxicity. These health-protective toxicity criteria are obtained through EPA-developed RfDs or SFs. The information used as part of the BRA toxicity assessment is presented in Appendix E.

D-1.1.5 Risk Characterization

Risk characterization involves combining the results of the toxicity and exposure assessments to provide a numerical estimate of health risk. This estimate is either a comparison of exposure levels with appropriate toxicity criteria or an estimate of the lifetime cancer risk associated with a particular intake. Risk characterization also considers the nature and weight of evidence supporting the risk estimate, as well as the magnitude of uncertainty surrounding the estimate. The results of the BRA risk characterization process, including risk estimates for each of the retained release sites, are presented in the site-specific tables of Appendix C and Appendix E. Risk characterization involves estimating the magnitude of the potential adverse human health effects from released COPCs. Specifically, risk characterization involves combining the results of the exposure and toxicity assessments to provide numerical estimates of health risk. These estimates are either comparisons of exposure levels with appropriate reference doses (RfDs) or estimates of the lifetime cancer risk with a given intake.

To quantify human health risks, contaminant intakes are calculated for each COPC by way of each applicable exposure route. These contaminant intakes are based on measured concentration estimates at each retained release site. To determine human health risks, the contaminant specific intakes are compared to the applicable chemical-specific toxicity data. The following subsections discuss the equations that are used to calculate risks for each retained site.

D-1.1.6 Estimates of Human Health Risk

Estimates of OU 10-04 human health risks during each evaluated time period are presented in Appendix E. For each time period, carcinogenic risks and noncarcinogenic HIs are shown in separate tables and figures.

Risk and HI estimates for the air and groundwater pathway exposure routes (i.e., inhalation of fugitive dust, inhalation of volatiles, ingestion of groundwater, dermal absorption of groundwater, and inhalation of water vapor from indoor water use) are calculated site-by-site or in a cumulative manner depending on the potential for cumulative impacts. For those evaluated cumulatively, the risk estimate for the exposure route is the same at each release site air or groundwater pathway exposure route within a given time period.

Risk and HQ estimates for ingestion of groundwater containing maximum predicted COPC concentrations are shown in Appendix E. These risk estimates are presented separately because the maximum predicted COPC concentrations may occur beyond the exposure time periods evaluated in the BRA.

D-1.1.7 Uncertainty Analysis

The risk assessment results presented in this BRA are very dependent on the methodologies described in this appendix. These analysis methods were developed over a period of several years by INEEL risk management and risk assessment professionals to provide realistic, yet conservative estimates of human health risks at WAG 6 and 10. Nonetheless, if different risk assessment methods had been used, the BRA likely would have produced different risk assessment results. To ensure that the risk estimates are conservative, health protective assumptions that tend to bound the plausible upper limits of human health risks are used throughout the BRA. Therefore, risk estimates that may be calculated by other risk assessment methods are not likely to be significantly higher than the estimates presented in this section.

The BRA results in Appendix E are useful for evaluating which WAG 6 and 10 sites require remediation because the results are calculated in a consistent manner. The consistency allows for direct comparison of the risk assessment results for a given site with the results for every other site included in the evaluation. Changes in a given assumption used in the evaluation would, in general, produce similar changes in the risk results for all of the sites evaluated. As described in the remainder of this section, the BRA results include inherent uncertainty, but despite this uncertainty, consistency of analysis makes the results useful for making remediation decisions.

Uncertainty in this BRA is produced by uncertainty factors in the following four stages of analysis:

1. Data collection and evaluation
2. Exposure assessment
3. Toxicity assessment
4. Risk characterization.

In the following subsections, each of these four stages is discussed in more detail, and a discussion of risks from potential future releases from co-located facilities within WAG 6 or 10 is presented in Section D-1.1.8.2.

D-1.1.7.1 Data Collection and Evaluation Uncertainties. Uncertainties associated with data collection and evaluation are produced by variability in observed concentrations from sampling design and implementation, laboratory analysis methods, seasonality, contaminant levels, and natural concentration. Making the most effective use of sampling data involves quantifying these uncertainties.

The effect of uncertainty introduced from sample collection and analysis is reduced by basing risk estimates on the 95% UCL of the mean for the WAG 6 and 10 COPC concentration estimates. The resulting concentration estimates, used to estimate intakes, are an upper-bound estimate of the concentrations observed at the retained sites. This approach provides protection for human health and accounts for the uncertainty introduced by sampling, analysis, seasonality, and natural variation.

A major assumption included in the BRA analysis is that all significant sources of contamination at WAGs 6 and 10 have been identified and sampled. If a source of contamination has not been identified and sampled, the risks from the contamination are not included in the BRA.

One of the first steps was a review of sites and screening contaminants as discussed in Appendix C. The purpose of the review was to help focus the BRA on sites and contaminants that are likely to produce adverse human health effects. The process was designed to be conservative so that all sites and contaminants that have a reasonable potential for causing adverse human health effects would be evaluated in the BRA. If in fact the process was not conservative enough and sites or contaminants that could cause adverse human health effects were inappropriately omitted, then the BRA risk results presented in Appendix E would be underestimated. A contamination source would have to be small to be inappropriately screened. Therefore, any underestimation of risk would be slight if a site or contaminant were inappropriately screened.

The contaminant screening process described in Appendix C used the EPA Region 3 or 9 risk-based concentrations as a screening criterion (EPA 1995). These concentrations were calculated based on a risk of 1E-06 and an HQ of 1.

The text included with the Region 3 screening tables recommends using one-tenth of the concentrations shown in the tables as the basis for contaminant screening. Region 9 recommends using the risk-based concentration (RBC) divided by the number of contaminants. The WAG 6 and 10 BRA assessed on the COPCs that screened based on the RBC. However a sensitivity analysis was conducted based on either one-tenth the RBC or the RBC divided by the number of contaminants. No additional COPCs were identified as being concerns. This sensitivity study is documented in the footnotes of the Appendix C screening tables.

This is considered acceptable because remedial decisions at the INEEL are generally based on the residential risk level of 1E-04. In other words, if a site's estimated residential risk exceeds a value of 1E-04, the site is typically considered for remedial action. The 1E-04 risk level is two orders of magnitude higher than the 1E-06 risk level that was used to calculate the risk-based concentration, so the 1E-06 risk-based concentrations are adequately protective.

In addition, the BRA methodologies for noncarcinogens are sufficiently conservative to preclude inappropriate remedial decisions that might result from screening contaminants. For example, the noncarcinogenic assessment used in the BRA implements upper-bound values for all exposure factors and treats all noncarcinogenic health effects additively (i.e., all noncarcinogens were assumed to produce adverse health impacts in the same organ). Decay of noncarcinogens in the environment is not considered. These conservative methods tend to produce upper-bound HQ estimates for all COPCs that passed the screening process and to increase the chance that a given site would be considered for remediation.

All of the sites evaluated in the BRA have varying levels of uncertainty associated with the contaminant concentrations evaluated in the BRA. In addition, all of the evaluated concentrations were estimated using conservative assumptions about the nature and extent of contamination at the various sites. The concentration term uncertainties and conservative assumptions are summarized in Table D-1.

As discussed in Section 4, the sampling results for all the retained sites were assumed to be lognormally distributed. This assumption is in accordance with guidance presented in EPA 1992b. In general, this assumption causes the 95% UCL calculations to produce higher average concentration estimates than would be produced if the sampling results were assumed to be normally distributed. If the

Table D-1. BRA human health assessment uncertainty factors.

Uncertainty Factor	Effect of Uncertainty	Comment
Source term assumptions	May overestimate risk	All contaminants are assumed to be completely available for transportation away from the source zone. In reality, some contaminants may be chemically or physically bound to the source zone and unavailable for transport.
Natural infiltration rate	May overestimate risk	A conservative value of 10 cm/year was used for this parameter.
Moisture content	May overestimate or underestimate risk	Soil moisture contents vary seasonally in the upper vadose zone and may be subject to measurement error.
Water table fluctuations	May slightly overestimate or underestimate risk	The average value used is expected to be representative of the depth over the 30-year exposure period.
Mass of contaminants in soils estimated by assuming a uniform contamination concentration in the source zone.	May overestimate or underestimate risk	There is a possibility that most of the mass of a given contaminant at a given site may exist in a hotspot that was not detected by sampling. If this condition existed, the mass of the contaminant used in the analysis might be underestimated. However, 95% upper confidence levels (UCLs) or maximum detected contamination were used for all mass calculations. These concentrations are assumed to exist at every point in each waste site; therefore, the mass of contaminants used in the analysis is probably overestimated.
Plug flow assumption in groundwater transport	Could overestimate or underestimate risk	Plug flow models are conservative relative to concentrations because dispersion is neglected, and mass fluxes from the source to the aquifer differ only by the time delay in the unsaturated zone (the magnitude of the flux remains unchanged). For nonradiological contaminants, the plug flow assumption is conservative because dispersion is not allowed to dilute the contaminant groundwater concentrations. For radionuclides, the plug flow assumption may or may not be conservative. Based on actual travel time, the radionuclide groundwater concentrations could be over or underestimated because a longer travel time allows for more decay. If the concentration decrease from the travel time delay is larger than the neglected dilution from dispersion, the model will not be conservative.
No migration of contaminants from the soil source prior to sampling	Could overestimate or underestimate risk	The result of not modeling contaminant migration from the soil before sampling is dependent on the contaminant half-life, radioactive ingrowth, and mobility characteristics.
Chemical form assumptions	Could overestimate or underestimate risk	In general, the methods and inputs used in contaminant migration calculations, including assumptions about chemical forms of contaminants, were chosen to err on the protective side. All contaminant concentration and mass are assumed available for transport. This assumption results in a probable overestimate of risk.

Uncertainty Factor	Effect of Uncertainty	Comment
Exposure scenario assumptions	May overestimate risk	The likelihood of future scenarios has been qualitatively evaluated as follows: Resident—improbable Industrial—credible. The likelihood of future onsite residential development is small. If future residential use of this site does not occur, then the risk estimates calculated for future on-site residents are likely to overestimate the true risk associated with future use of this site.
Exposure parameter assumptions	May overestimate risk	Assumptions about media intake, population characteristics, and exposure patterns may not characterize actual exposures.
Receptor locations	May overestimate risk	Groundwater ingestion risks are calculated for a point at the downgradient edge of an equivalent rectangular area. The groundwater risk at this point is assumed to be the risk from groundwater ingestion at every point within WAG 6&10 boundaries. Changing the receptor location will only affect the risks calculated for the groundwater pathway because all other risks are site-specific or assumed constant at every point within the WAG 6&10 boundaries.
For the groundwater pathway analysis, all contaminants were assumed to be homogeneously distributed in a large mass of soil.	May overestimate or underestimate risk	The total mass of each contaminant of potential concern (COPC) is assumed to be homogeneously distributed in the soil volume beneath each WAG 6&10 site/area. This assumption tends to maximize the estimated groundwater concentrations produced by the contaminant inventories because homogeneously distributed contaminants would not have to travel far to reach a groundwater well drilled anywhere within the WAG 6&10 boundary. However, groundwater concentrations may be underestimated for a large mass of contamination (located in a small area with a groundwater well drilled directly downgradient).
The entire inventory of each contaminant is assumed to be available for transport along each pathway	May overestimate risk	Only a portion of each contaminant's inventory will be transported by each pathway.
Exposure duration	May overestimate risk	The assumption that an individual will work or reside at a site for 25 or 30 years is conservative. Short-term exposures involve comparison to subchronic toxicity values, which are generally less restrictive than chronic values.
Noncontaminant-specific constants (not dependent on contaminant properties)	May overestimate risk	Conservative or upper bound values were used for all parameters incorporated into intake calculations.
Exclusion of some hypothetical pathways from the exposure scenarios	May underestimate risk	Exposure pathways are considered for each scenario and eliminated only if the pathway is either incomplete or negligible compared to other evaluated pathways.
Model does not consider biotic decay	May overestimate risk	Biotic decay would tend to reduce contamination over time.
Occupational intake value for inhalation is conservative	Slightly overestimates risk	Standard exposure factors for inhalation have the same value for occupational as for residential scenarios though occupational workers would not be onsite all day.

Uncertainty Factor	Effect of Uncertainty	Comment
Use of cancer slope factors	May overestimate risk	Slope factors are associated with upper 95th percentile confidence limits. They are considered unlikely to underestimate true risk.
Toxicity values derived primarily from animal studies	May overestimate or underestimate risk	Extrapolation from animal to humans may induce error from differences in absorption, pharmacokinetics, target organs, enzymes, and population variability.
Toxicity values derived primarily from high doses; most exposures are at low doses	May overestimate or underestimate risk	Assumes linearity at low doses. Tend to have conservative exposure assumptions.
Toxicity values and classification of carcinogens	May overestimate or underestimate risk	Not all values represent the same degree of certainty. All are subject to change as new evidence becomes available.
Lack of slope factors	May underestimate risk	COPCs without slope factors, may or may not be carcinogenic through the oral pathway.

sampling results for a given site were normally distributed, the calculated risks for the site would be overestimated as a result of the lognormal distribution assumption.

D-1.1.7.2 Exposure Assessment. Uncertainties associated with the exposure assessment are produced by characterizing transport, dispersion, and transformation of COPCs in the environment, establishing exposure settings, and deriving estimates of chronic intake. The initial characterization that defines the exposure setting for a site involves many professional judgments and assumptions. Definition of the physical setting, population characteristics, and selection of the chemicals included in the risk assessment are examples of areas for which a quantitative estimate of uncertainty cannot be achieved because of the inherent reliance on professional judgment.

An aspect of the risk assessment that tends to exaggerate risk results is the evaluation of contaminants with background concentrations that produce calculated risks in excess of 1E-06. An example of this type of contaminant is arsenic. This contaminant is commonly detected in INEEL soils at concentrations that are slightly higher than accepted risk-based concentrations. However, this contaminant is not associated with known waste-producing processes at WAG 6 or WAG 10, it falls within background concentrations discussed in Appendix K, and arsenic has very high toxicity constants. For these reasons, arsenic was not included in the risk assessment for some sites in which it has been detected. If the detected arsenic concentrations are in fact anthropogenic (i.e., produced by operations at the sites), the risk results for the sites would be underestimated.

Biotic transport is included in the preliminary conceptual site model (Appendix F) as a release mechanism because of the possibility that burrowing animals and nonagricultural plant uptake could transport contamination from depth up to the ground surface. The potential for biotic uptake was acknowledged in the WAG 6 and 10 RI/BRA, but biotic uptake modeling was not performed to quantify the effects of biotic uptake because most contaminant exposures calculated in the RI/BRA were based on average soil concentrations that were measured in the depth interval from 0 to 3 m (10 ft). In general, plants and animals at WAG 6&10 sites would not come into contact with soils that are at depths greater than 3 m (10 ft) below ground surface; therefore, biotic uptake generally will not affect the average concentrations used to calculate site exposures. To illustrate this point, consider a burrowing animal that moves contamination from a depth of 1 m (3 ft) up to the surface at a given site. The activity of this animal will not affect the calculated average concentrations from 0 to 3 m (10 ft) because the animal will simply be redistributing contamination within the site's depth interval from 0 to 3 m (10 ft).

The case in which biotic activity could affect the average concentrations used to calculate exposures in the RI/BRA is associated with the occupational exposure scenario. Most of the occupational scenario soil pathways and all of the occupational scenario air pathways were evaluated using average contaminant concentrations measured in the top 15 cm (6 in.) of soil. Including the effects of biotic uptake could change these average concentrations.

Despite the fact that the occupational exposure scenario average concentrations could be affected by biotic uptake, biotic uptake modeling was not performed to support the occupational scenario analysis for four reasons:

1. The occupational scenario evaluates a 100-year period of time when institutional controls will be in place at some of the WAG 6 and 10 sites. These controls will probably discourage biotic activity that would move large amounts of contamination to the surface.

2. The 100-year time period is a relatively short interval for the movement of contamination. Some contamination may be moved to the surface during this period, but the amount of transported contamination is expected to be small.

3. Many of the WAG 6 and 10 sites were created by surface releases of contamination. Biotic activity would tend to move clean soil from depth that would reduce the average concentrations in 0 to 15 cm (6 in.) depth interval at these sites.

4. All of the exposure parameters used in the occupational risk calculations were upper-bound values in accordance with EPA risk assessment guidance. These values cause the risk results to be upper-bound estimates, even if some of the concentration terms used at some of the sites were slightly underestimated. Not modeling biotic uptake in the occupational scenario evaluation is a source of uncertainty in the occupational scenario risk results, but this uncertainty is expected to be small in comparison to other uncertainties associated with the site concentration terms.

The only contaminant loss mechanism considered in the BRA is radioactive decay. Other loss mechanisms such as leaching and wind erosion are assumed to be negligible. The reason for this assumption is that environmental sampling has shown that most contaminants do not migrate from most INEEL sites. As a result of this observation, very few studies have been performed to evaluate these mechanisms. Therefore, very little site-specific information is available to estimate the exact effects of these removal mechanisms.

Omitting removal mechanisms other than radioactive decay tends to overestimate risk for all exposure routes because it leads to assuming a given mass of contaminant will cause exposures by multiple exposure routes. For example, leaching is omitted in the soil pathway analysis even though leaching is the mechanism that produces the contamination evaluated in the groundwater pathway analysis. As a result of the omission, a given mass of contamination can affect both the soil pathway and groundwater pathway risk analysis results. Upper-bound infiltration and contaminant leachability assumptions are used in the groundwater pathway analysis to estimate future groundwater contaminant concentrations. Applying these same upper-bound assumptions to the soil pathway analysis likely would produce an underestimation of soil pathway risks. To avoid this possibility, leaching is omitted from the soil pathway analysis, so that upper-bound risk results are calculated for both the soil pathway and groundwater pathway exposure routes.

One of the purposes of the BRA is to estimate upper-bound risks from WAG 6 and 10 contaminant releases based on best available site-specific information. Omitting removal mechanisms that have not been studied on a site-specific basis and that are likely to produce only small errors in the calculated risk results is consistent with this objective.

The residential exposure scenario evaluated in the BRA incorporates the assumption that potential future residents will dig into the contaminated sites at WAG 6 and 10 and spread the contaminated soil around their homes. As a result, the scenario simulates future residential exposure to average contaminant concentrations that exist in the top 3 m (10 ft) of the sites. This assumption is referred to as the residential intrusion assumption.

The intrusion assumption generally produces upper-bound risk estimates for release sites that have contamination located beneath the shallow surface soils. Averaging the deeper contamination with the shallow contamination produces an upper-bound estimate of the site's exposure point soil concentration. The intrusion assumption, however, does not produce upper-bound exposure estimates at sites that only have shallow surface contamination.

At a shallow surface release site, soil pathway risk estimates that are calculated using the 0 to 15 cm (0.5-ft) depth average concentration for a given contaminant would be higher than the estimates presented in the BRA. Specifically, the increase in the risk estimates would be equal to the ratio of the

contaminant's 0 to 15 cm (0.5-ft) concentration. For example, if a site had a 0 to 15 cm (0.5-ft) average concentration for a given contaminant of 100 mg/kg, a 0 to 3 m (10-ft) average concentration of 10 mg/kg, and a calculated residential soil ingestion risk equal to 1E-06, the soil ingestion risk that would be calculated using the 0 to 15 cm (0.5-ft) average concentration would equal 1E-05 [1E-06 × (100 mg/kg)/(10 mg/kg) = 1E-05]. This example illustrates that the depth of intrusion for potential future residents is a significant source of uncertainty in the BRA exposure assessment. WAG 6&10 sites in which the intrusion assumption may not be conservative can be identified by comparing the 0 to 15 cm (0.5-ft) concentration for a given COPC, as shown in Appendix E, to the 0 to 10-ft average concentration for the contaminant.

D-1.1.8 Toxicity Assessment

Several important measures of toxicity are needed to conduct an assessment of risk to human health. Reference doses are applied to the oral and inhalation exposure to evaluate noncarcinogenic and developmental effects, and slope factors (SFs) are applied to the oral and inhalation exposures to carcinogens. Reference doses are derived from no-observed-adverse-effect levels (NOAELs) or lowest observed-adverse-effect levels (LOAELs), and the application of uncertainty factors and modifying factors. Uncertainty factors are used to account for the variation in sensitivity of human subpopulations and the uncertainty inherent in extrapolation of the results of animal studies to humans. Modifying factors account for additional uncertainties in the studies used to derive the NOAEL or LOAEL. Uncertainty associated with SFs is accounted for by an assigned weight-of-evidence rating that reflects the likelihood of the toxicant being a human carcinogen. Weight-of-evidence classifications are tabulated in Table E4-1 in Appendix E.

D-1.1.8.1 Risk Characterization. The last step in the risk assessment is risk characterization. As discussed in Section 4, risk characterization is the process of integrating the results of the exposure assessment and the toxicity assessment. The uncertainties defined throughout the analysis process are combined and presented as part of the risk characterization to provide an understanding of the overall uncertainty in the estimate of risk. This qualitative assessment of uncertainty is presented in Table D-1. See Appendix E for a complete presentation of the risk estimates and Section 18 for a summary of WAG 6&10 risks.

Because some of the contaminants detected at WAG 6 and 10 release sites do not have available toxicity information (e.g., lead, chloride, sulfate, and 2-pentanone), risks and hazard quotients could not be calculated for these contaminants. As a result, if the contaminants have the potential for producing adverse health impacts, the risks and hazard quotients at the release sites that contain these contaminants may be underestimated.

D-1.1.8.2 Uncertainties in the Facilities Assessment Analysis. As discussed in Section 6, the facilities assessment analysis examined the potential contributions to risk from discontinued, ongoing, and future operations at WAG 6. Buildings and structures with a history of releases not under current, appropriate management controls and those that possess the potential to impact cumulative risk at WAG 6 sites would be retained for consideration in the BRA. However, no such facilities or structures were identified in the facilities assessment analysis for EBR-I.

Management controls are adequate to address contaminant releases from EBR-I site and HTRE assemblies to the environment from facility activities. All historical releases have either been remediated in the past or have been identified with a WAG 6 CERCLA site.

In the future, the facility assessment sites will undergo deactivation, decontamination, and decommissioning (D&D&D). As always, the general objective of D&D&D is to take all reasonable

measures to minimize worker exposure to radiological, chemical, and industrial hazards and prevent the release of contaminants to the environment. It is possible that D&D&D will discover a past release, but all of the CERCLA sites at EBR-I are relatively remote from the risk issues identified for the facility assessment sites. It is unlikely any D&D&D discovery would affect the risk calculations for the CERCLA sites. When D&D&D is complete, WAG 6 will resume management of EBR-I and evaluate any potential residual risk.

The facilities assessment analysis did not identify any additional sites for evaluation in the WAG 6&10 comprehensive RI/BRA. The analysis was based on the assumptions that appropriate management controls will be maintained and enforced to ensure future protection of human health and the environment and that all significant historical releases within WAG 6 have been identified. The uncertainty associated with these two assumptions cannot be quantified but is qualitatively considered very low.

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